6 - EFDC WATER QUALITY MODEL CALIBRATION

The EFDC hydrodynamic and water quality model was used to determine the receiving water quality conditions in the tidal and non-tidal streams in the Christina River Basin. Nutrient loads were input to the EFDC model by means of linkage to the HSPF watershed loading models and the XP-SWMM CSO simulation flow model. Flows and loads from over 100 NPDES facilities were also included in the EFDC model.

6.1 Modeling Assumptions

The main objective of applying the EFDC model was to develop hydrodynamic and water quality information for the primary stream channels throughout Christina River Basin. Specifically, it was necessary to accurately understand the variability of flow throughout the stream network under variable flow conditions. Major assumptions that contributed to the final approach taken included:

- The waterbody was well mixed laterally and vertically, therefore a longitudinal one-dimensional configuration was appropriate for the freshwater stream channels.
- Thermal stratification was not likely due to the shallow and narrow characteristics of the creek, thus temperature is not an important driving force for flow and transport.
- Wind effects on flow and transport were not a critical factor due to the one-dimensional flow pattern.
- The impact of groundwater interaction on flow and transport was minimal during low flow conditions, thus flow distribution can be obtained through directly balancing upstream and downstream flow rates.

6.2 Model Configuration

The general procedure for application of the EFDC model to the Christina River Basin followed a sequence of steps beginning with model configuration and continued through model execution of the calibration time period. Model configuration involved the construction of the horizontal grid for the waterbodies in the basin, interpolation of bathymetric data to the grid, construction of EFDC input files, and compilation of the Fortran source code with appropriate parameter specification of array dimensions. The model included 120 NPDES point-source discharges and 28 consumptive use water withdrawals. The locations of the NPDES discharges are shown in Figure 6-1. Schematic drawings of the EFDC grid configuration are presented in Appendix C. The locations of the NPDES discharges relative to EFDC grid cells are shown in Figure C-1. The locations of the water withdrawals are shown in Figure C-2. The EFDC model also included flows and loads from 38 CSO discharges and was linked to the HSPF watershed loading models to incorporate nonpoint source flows and loads.

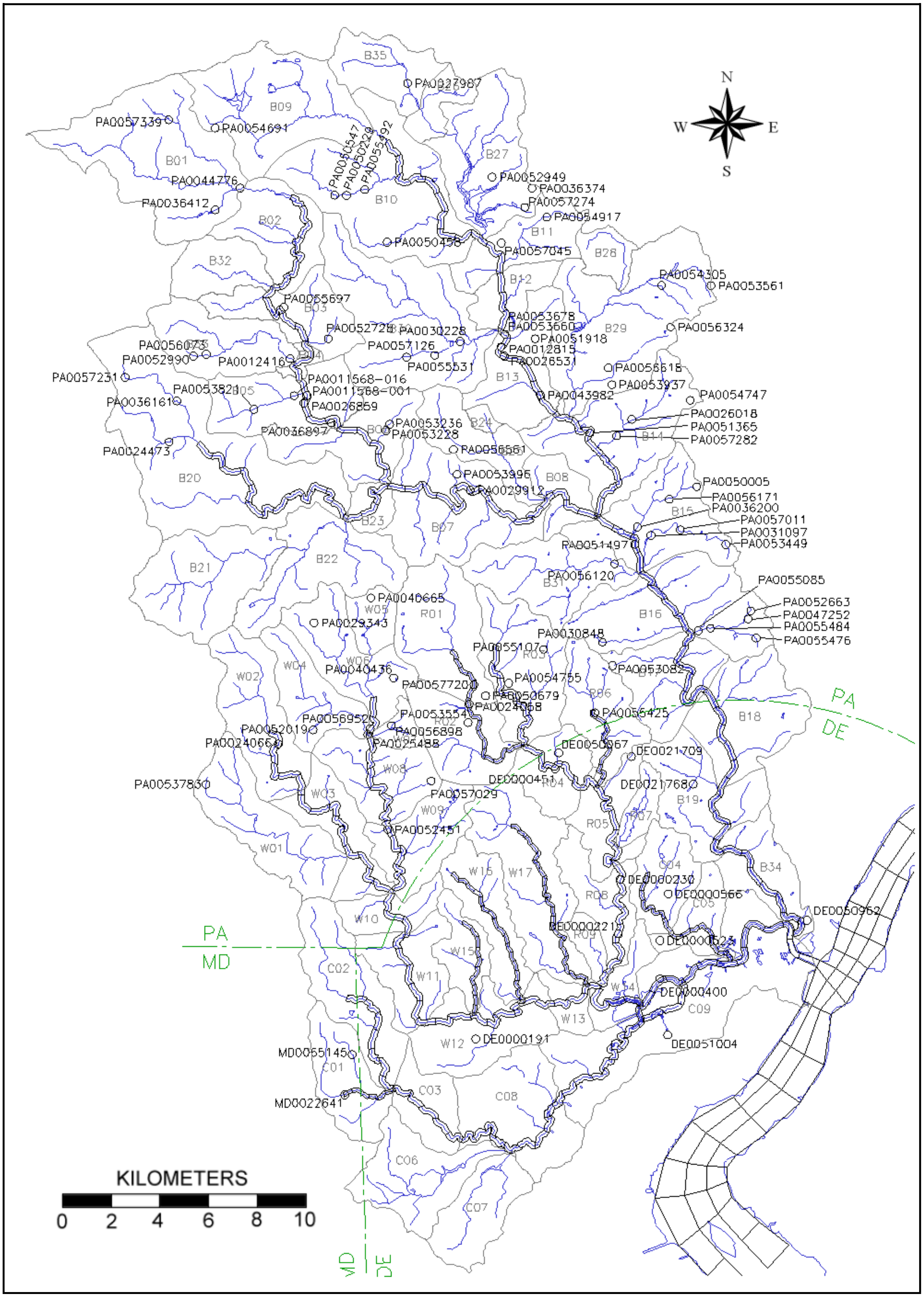

Figure 6-1. Locations of NPDES discharges in Christina River Basin.

6.2.1 Segmentation

The numerical model domain includes the tidal Delaware River from Reedy Point on the south to Chester on the north. Both the tidal and nontidal Christina River reaches are included in the model. The lower Christina River is directly connected to the Delaware River. The nontidal Christina River is connected to the tidal portion by a dam control structure at Smalleys Pond. The tidal Brandywine Creek is connected to the tidal Christina River by means of a tidal inlet control structure. The tidal White Clay Creek is also connected to the tidal Christina River via a tidal inlet control structure.

The basic equations in EFDC were solved using the finite-difference method. The grid was designed to resolve velocity shears both axially and laterally, and at the same time allow a time step suitable for efficient computation. Solutions to the hydrodynamics were obtained using a 60-second time step. The spatial domain of the study area was divided into a grid of discrete cells. To achieve close conformance of the grid to the estuary geometry, the cells in the Delaware River were represented using curvilinear horizontal grid cells constructed using an orthogonal mapping procedure (Ryskin and Leal 1983) to form a 2-D grid domain. The cells in the narrow tidal and nontidal streams were represented by a 1-D Cartesian coordinate system (see Figure C-1). To obtain adequate resolution in the streams, longitudinal cells were configured according to lengths ranging from 500 to approximately 1,000 meters. Cell widths were adjusted according to estimated wetted stream channel widths under low-flow conditions. Velocities were computed on the boundaries between cells, and temperature, salinity, and density were computed at the center of each cell. The numerical grid consisted of 406 cells in the horizontal plane and a single vertical layer. A single layer was chosen because the estuary and streams are well mixed, thereby implying that stratification would not be an issue. In addition, field data available from STORET and from Davis (1998) did not distinguish vertical sample depths.

6.2.2 Streamflow Estimation

Variable streamflow discharge was estimated using flows from the HSPF model for the calibration period 1994-1998. The streamflow was validated using observed daily average flows at several USGS stream gages throughout the Christina River Basin (Senior and Koerkle, (2003a, 2003b, 2003c, and 2003d).

6.2.3 Atmospheric and Tidal Boundary Conditions

Atmospheric nutrient loads are typically divided into wet and dry deposition. Wet deposition is associated with dissolved substances in rainfall. The settling of particulate matter during non-rainfall events contributes to dry deposition. Observations of concentrations in rainwater are frequently available, and dry deposition is usually estimated as a fraction of the wet deposition. The atmospheric deposition rates reported in the Long Island Sound Study (HydroQual, 1991) and the Chesapeake Bay Model Study (Cerco and Cole, 1993) as well as information provided by DNREC for Lewes, Delaware, were used to develop both dry and wet deposition loads for the EFDC model of the Christina River Basin (see Tables 6-1 and 6-2). Meteorological information (i.e., atmospheric pressure, temperature, relative humidity, wind speed and direction, rainfall, cloud cover, and solar radiation) was obtained from the NOAA National Climatic Data Center weather station (WBAN 13781) at the New Castle County Airport near Wilmington, Delaware.

Table 6-1. Atmospheric dry deposition rates used in Christina River Basin EFDC model.

Parameter	Deposition Rate ($g/m^2/day$)	Parameter	Deposition Rate ($g/m^2/day$)
Refractory Part. Organic Carbon	0.000387	Refractory Part. Organic Nitrogen	0.000530
Labile Part. Organic Carbon	0.000387	Labile Part. Organic Nitrogen	0.000530
Dissolved Organic Carbon	0.000773	Dissolved Organic Nitrogen	0.000771
Dissolved Organic Phosphorus	0.000054	Ammonia Nitrogen	0.000214
Orthophosphate	0.000019	Nitrate+Nitrite Nitrogen	0.000393
Available Silica	0.000247		

Table 6.2. Atmospheric wet deposition concentrations used in Christina River Basin EFDC model.

Parameter	Concentration (mg/L)	Parameter	Concentration (mg/L)
Refractory Part. Organic Carbon	0.325	Refractory Part. Organic Nitrogen	0.0
Labile Part. Organic Carbon	0.325	Labile Part. Organic Nitrogen	0.0
Dissolved Organic Carbon	0.650	Dissolved Organic Nitrogen	0.140
Dissolved Organic Phosphorus	0.045	Ammonia Nitrogen	0.222
Orthophosphate	0.016	Nitrate+Nitrite Nitrogen	0.332
Available Silica	0.0		

Tides were specified at the north and south boundaries in the Delaware River based on the astronomical harmonic constants for the NOAA subordinate tide stations at Reedy Point, Delaware (south boundary) and Chester, Pennsylvania (north boundary). The predicted tides from the harmonic constants do not include any low-frequency influences due to storms or regional low-pressure conditions (NOAA, 1998)..

The specification of boundary conditions was required at the model north and south interface with the Delaware River. The EFDC water quality model accommodates 21 boundary variables, each specified in an individual time-series data file of concentrations. Advective boundary conditions in the Christina River model were of the “upwind” type. Evaluation of the boundary concentration depended on the direction of flow at the boundary. When flow was out of the model, the boundary concentration was assigned the concentration in the model cell immediately upstream of the boundary. When the tidal flow was into the model, the boundary concentration was assigned a specified, time-varying value representative of conditions outside the model domain. To estimate recirculation at the boundary near the time of flow reversal from outgoing to incoming tide, the last outgoing concentration at the boundary is used as the incoming concentration for a certain amount of time specified by the user. This concentration linearly approaches the specified outside boundary concentration over that time period. For the Christina River model, the recirculation time interval was specified as 60 minutes based on experience gained from previous water quality model applications of the EFDC model.

Delaware River boundary conditions for salinity, temperature, total suspended sediment, algae, organic carbon, dissolved oxygen, nitrogen, phosphorus, silica, and fecal coliform bacteria were specified based on available STORET data at stations in the Delaware River. The boundary time-series were created using observations that were averaged by month over the simulation period. If data for a parameter were not available for any given month, then the long-term average (over the period 1988-1998) for that month was used instead.

6.2.4 Initial Conditions

Initial conditions for freshwater streams in the EFDC model at the starting time of October 1, 1994, were estimated using the simulated flows and nutrient concentrations calculated by the HSPF model. Initial water quality concentration conditions in the tidal Delaware River and tidal Christina River were estimated using the ending conditions from the 1995 low-flow validation run (September 30, 1995). These initial conditions allow the model to begin its simulation at a stable numeric state. The impacts of initial conditions diminish quickly with time.

6.2.5 Point and Nonpoint Source Representation

External flows and loads of nutrients and oxygen demand were divided into four categories: (1) nonpoint source loads (i.e., diffuse sources) including tributary sources and groundwater sources, (2) point-source, (3) water withdrawals, and (4) atmospheric deposition. Nonpoint source loads were carried by freshwater flows and groundwater entering the main stream reaches. Point-source loads were discharges from the NPDES facilities and CSOs in the study area. Consumptive use water withdrawals were removed from the model system at the appropriate grid cell. Atmospheric loads were transfers from the atmosphere to the water surface via rainfall (wet deposition) and other processes (dry deposition). Atmospheric deposition is not a significant source in the narrow stream channels, but may be more important in the open estuary waterbodies in the lower Christina River and Delaware River because of the larger water surface area in those regions.

Nonpoint sources were estimated by the delineation of subbasins and land use categories in the HSPF watershed loading models. The nonpoint source loads generated by the watershed models provided predictive nutrient loads to the receiving waters reflective of variable meteorological (rainfall-runoff) characteristics.

Discharge Monitoring Records (DMRs) for various NPDES point sources in the Brandywine Creek watershed were provided in hard copy form by the Brandywine Valley Association. Other DMRs were provided in electronic format by PADEP and DNREC. The hard-copy data were keypunched and the electronic data were reformatted into a database file for use in developing point source loads for the water quality model. A list of all 120 NPDES discharges included in the model is given in Appendix C (Table C-1). The August 1997 field monitoring study (Davis 1998) included seven NPDES discharges that were monitored for flow and water quality parameters (see Appendix C, Figure C-3). Loading values for the various water quality constituents were computed based on the flow rates and concentrations provided on the DMRs or measured during the August 1997 study.

The NPDES discharges included single residence discharges (SRD) that are not required to submit DMR data. For purposes of model calibration, it was assumed that these SRD discharges operated at their permit discharge limits. Characteristic concentrations for the various water quality parameters were assigned to the NPDES source based on the type of discharge, and the loading in kg/day for each constituent was computed for input to the EFDC model. The characteristic effluent concentrations used for this study are listed in Appendix C, Table C-2, and the characteristic effluent parameter ratios are listed in Table C-3. The characteristic effluent concentrations and parameter ratios were derived from effluent monitoring data collected by Davis (1998) in August 1998 and from literature values reported in the *Technical Guidance Manual for Developing TMDLs* (USEPA, 1995).

For model calibration, a time-series of monthly average loads for the 1994-1998 simulation period was developed for nutrients, dissolved oxygen, CBOD, and total suspended solids for each NPDES point source based on available discharge monitoring records (DMRs). The methodology for estimating the various species of nitrogen and phosphorus is outlined in Table 6-3 and was described in the low-flow modeling report (USEPA, 2000). The ratios for converting CBOD5 to organic carbon for the model were determined based on data collected during a special study conducted in August-September 1999 from several of the larger WWTPs in the basin (USEPA, 2000).

Table 6-3. Methodology for developing EFDC point source loads from DMR data.

Water Quality Parameter	EFDC Code	Calculation
CBOD-5-day		CBOD5 = BOD5 * (CBOD5:BOD5 ratio)
CBOD-ultimate		CBODu = CBOD5 * (CBODu:CBOD5 ratio)
Total organic carbon	TOC	TOC = CBODu * (TOC:CBODu ratio)
Dissolved organic carbon	DOC	DOC = TOC * (DOC:TOC ratio)
Refractory particulate organic carbon	RPOC	0.5 * (TOC - DOC)
Labile particulate organic carbon	LPOC	0.5 * (TOC - DOC)
Total phosphorus Total organic phosphorus		If TP not reported on DMR, use default TP from Table C-2 TOP = TP - (TP * (OPO4:TP ratio))
Refractory particulate organic phosphorus	RPOP	0.25 TOP
Labile particulate organic phosphorus	LPOP	0.25 TOP
Dissolved organic phosphorus	DOP	0.50 TOP
Total orthophosphate	PO4T	TP * (OPO4:TP ratio)
Total nitrogen Nitrite nitrogen Total organic nitrogen		TN = NH3-N * (TN:NH3 ratio) NO2-N = NH3-n * (NO2:NO3 ratio) TON = TN - NO2-N - NO3-N - NH3-N
Refractory particulate organic nitrogen	RPON	0.25 TON
Labile particulate organic nitrogen	LPON	0.25 TON
Dissolved organic nitrogen	DON	0.50 TON
Ammonia nitrogen	NH3	reported on DMR (or use default NH3-N from Table C-2)
Nitrate nitrogen	NO3	NO3-N = NH3 * (NO3:NH3 ratio)
Unavailable biogenic silica	SUU	0.10 mg/L (default value)
Dissolved available silica	SAA	1.00 mg/L (default value)
Chemical oxygen demand	COD	9.6 * CBOD5
Dissolved oxygen	DOO	reported on DMR (or use default value from Table C-2)
Total active metal	TAM	0.0 (not simulated)
Fecal coliform bacteria	FCB	reported on DMR (or use default value from Table C-2)

CSO flows were estimated using XP-SWMM and were provided by the City of Wilmington. Nutrient loads from CSO outfalls were estimated using the XP-SWMM flow rates and event mean concentrations based on storm event monitoring conducted by the City of Wilmington and Delaware DNREC (see Tables 2-1a, b, and c).

6.2.6 Time Step and Simulation Duration

The EFDC model was executed at a time step of 60 seconds and the calibration simulated four consecutive water years covering the period from October 1, 1994 to October 1, 1998. A listing of the key EFDC input data files is presented in Appendix D.

6.3 Model Calibration Results

Model calibration involves the adjustment of certain model input quantities in an attempt to achieve a specified level of model performance. An extensive set of field data were gathered, processed, and displayed for modeling hydrodynamics and water quality transport in the Christina River Basin. The data set included database files containing more than 40,000 records at about 200 stations scattered throughout the interior of the basin as well as in the Delaware River itself. This section presents the results of the calibration of the EFDC hydrodynamic and water quality model. Parameters considered for calibration include flow rate and a suite of water quality parameters including nitrogen, phosphorus, carbon, and dissolved oxygen.

6.3.1 Tide Elevation and Phase

Calibration of the model with respect to water surface elevation was accomplished by analysis of observed and model predicted time-series data at two interior tide stations. For tidal waters, least squares harmonic analysis is the most commonly utilized procedure (Oey, Mellor, and Hires, 1985; Cheng et al., 1993; Shen et al., 1999). Tide elevation data were obtained from the USGS tide stations on the Christina River at the Port of Wilmington near the mouth and at Newport about 7.0 miles upstream of the mouth. These data were compared with surface elevations computed by the model at cell 56,13 (Port of Wilmington) and 45,13 (Newport). The time-series of tide elevations for the month of August 1997 for both the field data and model results were subjected to a harmonic analysis. The five most important astronomical harmonic constituents (M2, S2, N2, K1, and O1) were computed for both the field data and model simulation results. The harmonic analysis results, shown in Table 6-4, indicate the model is in good agreement with the measured tide data for both amplitude and phase. The model-data amplitudes for the M2 harmonic constituent agree within 5 cm (6%) and the phases agree to within 4 degrees (3%). Time-series graphs (Appendix C, Figure C-4) of the observed and model tide elevations at both the Port of Wilmington and Newport covering a 15-day period (August 1 - 15, 1997) provide a visual means of assessing the skill of the model in simulating tidal elevations. The model tides are forced at the north and south boundaries in the Delaware River based on the NOAA predictions at the Reedy Point, DE, and Chester, PA, subordinate stations (NOAA, 1998).

Table 6-4. Harmonic analysis of tides at Port of Wilmington and Newport

Harmonic Constant	Port of Wilmington		Newport	
	Amplitude (m)	Phase (degrees)	Amplitude (m)	Phase (degrees)
M2 - observed	0.7594	130.382	0.6901	153.634
M2 - model	0.7135	134.180	0.6768	155.560
Difference	0.0459	-3.798	0.0133	-1.926
S2 - observed	0.0894	20.621	0.0900	36.374
S2 - model	0.1001	30.806	0.0890	59.180
Difference	-0.0107	-10.185	0.0010	-22.806
N2 - observed	0.1271	323.153	0.1275	345.054
N2 - model	0.1383	336.181	0.1240	3.603
Difference	-0.0112	-13.028	0.0035	-18.549
K1 - observed	0.0802	174.059	0.0615	184.740
K1 - model	0.0633	178.335	0.0606	190.948
Difference	0.0169	-4.276	0.0009	-6.208
O1 - observed	0.0626	316.879	0.0546	332.386
O1 - model	0.0546	326.765	0.0514	337.937
Difference	0.0080	-9.886	0.0032	-5.551

6.3.2 Water Depth and Stream Velocity

Measurements of flow, water depth, and stream velocity were made at eight locations during the August 1997 field survey (Davis, 1998). The field measurements were made on the following dates: East Branch Brandywine Creek (08/12 - 08/14/1997), West Branch Brandywine Creek (08/19 - 08/20/1997), West Branch Red Clay Creek (08/05 - 08/07/1997 and 08/12 - 08/14/1997), and East Branch White Clay Creek (08/26 - 08/28/1997). A comparison of these measurements with the model results at the appropriate grid cell (I,J) location is given in Table 6-5.

Table 6-5. Model-data comparison of velocity, flow, and geometry (August 1997 data).

Stream Reach	EFDC Cell	Velocity (fps)		Depth (ft)		Flow (cfs)		Channel Width (ft)	
		Field	EFDC	Field	EFDC	Field	EFDC	Field	EFDC
East Branch Brandywine Creek	54,61	0.33	0.48	0.82	0.87	14.5	25.6	53.6	52.5
East Branch Brandywine Creek	54,56	0.85	0.56	1.02	1.11	34.3	34.5	39.6	52.5
West Branch Brandywine Creek	19,79	0.40	0.41	1.09	0.94	9.5	14.9	45.0	42.6
West Branch Brandywine Creek	26,79	0.41	0.36	0.70	0.82	32.0	32.9	111.5	111.5
East Branch White Clay Creek	19,31	0.44	0.40	0.93	0.96	5.30	5.33	13.0	12.8
East Branch White Clay Creek	19,29	0.42	0.41	0.85	0.86	7.35	7.34	20.6	20.3
West Branch Red Clay Creek	29,43	0.35	0.44	0.75	0.78	3.55	3.35	13.5	13.5
West Branch Red Clay Creek	33,43	0.49	0.52	0.90	0.94	5.45	4.92	12.4	12.4

6.3.3 Sediment Oxygen Demand and Benthic Nutrient Flux Rates

The need for a predictive benthic sediment processes model for water quality modeling projects has been apparent for some time. When using a water quality model for management scenario analysis, one of the biggest sources of uncertainty involves what to use for the future sediment flux rates after a proposed management control has been implemented. The predictive sediment submodel in EFDC helps address this uncertainty with two fundamental capabilities: (1) the ability to predict effects of management alternatives on sediment-water exchange processes and (2) the ability to predict the time scale for alterations in the sediment-water exchange processes. To meet these requirements, a predictive sediment process model was incorporated into the EFDC model framework and was based on DiToro and Fitzpatrick (1993). The sediment submodel is driven by net settling of organic matter from the water column to the sediments. In the benthos, the sediment submodel simulates the decay (diagenesis) of organic matter, which produces oxygen demand and inorganic nutrients. Oxygen demand takes three paths out of the sediments: (1) export to the water column as chemical oxygen demand, (2) oxidation at the sediment-water interface as sediment oxygen demand, or (3) burial to a deep, inactive sediment layer. The inorganic nutrients produced by diagenesis can take two pathways out of the bottom sediment: (1) release back to the overlying water column or (2) burial to the deep, inactive sediment layer.

In the predictive sediment submodel, benthic sediments are represented as two layers with a total depth of 10 cm. The upper benthic layer is in contact with the water column and may be oxic or anoxic depending on the dissolved oxygen concentration in the water. The lower benthic layer is permanently anoxic. The thickness of the upper benthic layer is determined by the penetration of oxygen into the sediments, and at its maximum thickness, the oxic layer depth is a small fraction of the total thickness. The sediment submodel consists of three basic processes:

- Particulate organic matter settles from the water column to the sediments. Because of the negligible thickness of the upper benthic layer, deposition proceeds from the water column directly to the lower anoxic layer.

- Within the lower layer, organic matter is subject to decay (diagenesis).

- The flux of substances produced by diagenesis moves to the upper benthic layer, to the water column, and to the deep, inactive benthic layer (burial). The flux portion of the sediment submodel is the most complex. The computation of flux requires consideration of (1) reactions in both benthic layers, (2) sedimentation from the upper to lower benthic layer as well as from the lower benthic layer to the deep inactive sediments, (3) particle mixing between layers, (4) diffusion between layers, and (5) mass transfer between the upper layer and the water column.

Very limited field data were available during the calibration period to verify the flux rates computed by the predictive sediment submodel. SOD rates were measured in July and August 1996, at three locations in the tidal Christina River and Brandywine Creek. An SOD rate of 0.5 g/m^2/day was used in the tidal Delaware River in another model study commissioned by the Delaware River Basin Commission (DRBC) and was used as the basis for comparison to predicted SOD rates from this study. The simulated SOD rates were converted to rates at 20°C and are compared with the measured data in Table 6-6. The relative errors were less than 13% at all locations, which is considered to be a very good model-data skill assessment.

Table 6-6. Model-data comparison of sediment oxygen demand rates (g/m^2/day)

Location	Sampling Date	Monitored SOD at 20°C	EFDC Model SOD at 20°C	Relative Error
Christina River at I-495 bridge	Aug 12, 1996	0.81	0.91	12.9%
Christina River at Newport, Rt. 141 bridge	Jul 10, 1996	1.67	1.56	6.5%
Brandywine Creek, 0.6 mi. from mouth	Aug 12, 1996	1.23	1.19	3.4%
Delaware River (from HydroQual study)	-	0.50	0.46	8.8%

6.3.4 Water Quality Results

Each field observation was collected at an instant in time and at a single point in space. Time scales realistically represented in the EFDC model were determined by time scales of primary forcing functions: 60-second tidal hydrodynamics time-step, hourly meteorological inputs, monthly ocean boundary conditions, daily nonpoint source loads, monthly point source loads, daily CSO loads, constant atmospheric dry deposition, and hourly atmospheric wet deposition during rain events. The minimum model spatial scales were determined by the size of the grid cells, ranging from 500 to about 1,000 meters in the longitudinal direction along the streams. The disparity in the temporal and spatial scales between the model and prototype, especially for the nonpoint and point source loads, meant that individual observations may not be directly comparable with model prediction at a specific time in a given model grid cell.

Model-data comparisons were be made qualitatively (time-series graphics) and quantitatively (model-data statistics). The time-series graphics are provided in Appendix A and cover the entire 4-year calibration period beginning Oct 1, 1994 and continuing to Oct 1, 1998. The model-data time-series comparison graphics were made at 27 monitoring locations on various streams in the study area (see the map in Appendix A, Figure A-0).

The graphical model-data time-series comparisons in Appendix A provide a qualitative evaluation of model performance. A seasoned modeler can examine the plots and form an experience-based judgment on the status of model calibration and verification. The model-data statistical analysis provides a different perspective on model-data comparison that numerically quantifies the state of model calibration/verification (sometimes referred to as model "skill assessment").

Although numerous methods exist for analyzing and summarizing model performance, there is no consensus in the modeling community on a standard analytical suite. A set of basic statistical methods were used to compare model predictions and sampling observations which included the mean error statistic, the absolute mean error, the root-mean-square error, and the relative error. Statistics for the observations and model predictions were calculated over the period Oct 1, 1994 to Oct 1, 1998 at 24 monitoring locations in the Christina River Basin (see Table 6-7 and the map in Appendix A, Figure A-0).

Table 6-7. Monitoring stations used for time-series model-data statistical analysis

Station	EFDC grid cell (I,J)	Stream and Location
104011	54,20	Brandywine Creek at Brandywine Park
104021	54,23	Brandywine Creek at Road 279
104051	54,32	Brandywine Creek at Smith Bridge
WQN0105	54,36	Brandywine Creek
103041	43,38	Red Clay Creek at Ashland, DE
103061	48,52	Burroughs Run at Rt. 241
103031	43,30	Red Clay Creek at Woodale, DE
103011	43,24	Red Clay Creek at Stanton, DE
WQN0149	19,18	White Clay Creek
105031	21,18	White Clay Creek at Road 329 near Thompson
105011	41,18	White Clay Creek at Rt. 7 in Stanton
105131	31,34	Muddy Run at Road 303
105071	31,40	Mill Creek at Road 282
106191	14,13	Christina River above Newark at Rt. 273
106141	22,13	Christina River at Road 26
106031	32,13	Christina River at Smalleys Pond
106021	47,13	Christina River at Rt. 141 in Newport
106011	53,13	Christina River at US Rt. 13
106291	55,13	Christina River at RR Bridge near Port of Wilmington
106281	43,55	Little Mill Creek at Atlantic Avenue
BCWB05	27,79	Brandywine Creek West Branch at Modena, PA
BCWB04	21,79	Brandywine Creek West Branch at Coatesville, PA
BCEB02	54,55	Brandywine Creek East Branch below Downingtown, PA
RCWB02	29,43	Red Clay Creek West Branch near Kennett Square, PA

6.3.4.1 Mean Error Statistic. The mean error between model predictions and observations is defined in Eq. 6-1. A mean error of zero is ideal. A non-zero value is an indication that the model may be biased toward either over- or underprediction. A positive mean error indicates that on average the model predictions are less than the observations. A negative mean error indicates that on average the model predictions are greater than the observed data. The mean error statistic may give a false ideal value of zero (or near zero) if the average of the positive deviations between predictions and observations is about equal to the average of the negative deviations in a data set. Because of that possibility, it is never a good idea to rely solely on this statistic as a measure of performance. Instead, it should be used in tandem with the other statistical measures that are described in this section.

$$E = \frac{\Sigma\ (O - P)}{n} \tag{6-1}$$

where:

E = mean error
O = observation, aggregated by month and over the water column
P = model prediction, aggregated by month and over vertical layers
n = number of observed-predicted pairs

6.3.4.2 Absolute Mean Error Statistic. The absolute mean error between model predictions and observations is defined in Eq. 6-2. An absolute mean error of zero is ideal. The magnitude of the absolute mean error indicates the average deviation between model predictions and observed data. Unlike the mean error, the absolute mean error cannot give a false zero.

$$E_{abs} = \frac{\Sigma\ |O - P|}{n} \tag{6-2}$$

where:

E_{abs} = absolute mean error.

6.3.4.3 Root-Mean-Square Error Statistic. The root-mean-square error (E_{rms}) is defined in Eq. 6-3. A root-mean-square error of zero is ideal. The root-mean-square error is an indicator of the deviation between model predictions and observations. The E_{rms} statistic is an alternative to (and is usually larger than) the absolute mean error.

$$E_{rms} = \sqrt{\frac{\Sigma\ (O - P)^2}{n}} \tag{11-3}$$

where:

E_{rms} = root-mean-square error

6.3.4.4 Relative Error Statistic. The relative error between model predictions and observations is defined in Eq. 6-4. A relative error of zero is ideal. The relative error is the ratio of the absolute mean error to the mean of the observations and is expressed as a percent.

$$E_{rel} = \frac{\Sigma\ |O - P|}{\Sigma\ O} \tag{6-4}$$

where:

E_{rel} = relative error.

6.3.4.5 Statistics Results. A summary of the error statistics for eight key water quality parameters of the Christina River Basin model calibration simulation is given in Table 6-8. The relative error statistic permits comparisons between the various water quality substances. Temperature and dissolved oxygen were the parameters with the smallest relative error. The results for temperature indicate a relative error of about 5.5%, and the relative error for dissolved oxygen was less than 8.3%. The relative error for total nitrogen was about 15%, ammonia nitrogen was 41%, total phosphorus was about 29%, total organic carbon was less than 18%, and dissolved organic carbon was about 30%.

Table 6-8. Statistical summary of EFDC water quality model 1994-1998 calibration results

Parameter	Mean Error	Absolute Mean Error	RMS Error	Relative Error	Number of Samples
Dissolved Oxygen (mg/L)	-0.2777	0.7587	1.1401	8.21%	859
Total Organic Carbon (mg/L)	0.5409	1.1434	2.0986	17.70%	820
Diss. Organic Carbon (mg/L)	1.2370	1.6205	2.3721	30.11%	818
Total Nitrogen (mg/L)	0.1979	0.4579	0.7880	15.20%	778
Ammonia Nitrogen (mg/L)	0.0107	0.0284	0.0545	40.96%	774
Nitrate Nitrogen (mg/L)	0.0373	0.3285	0.5041	13.94%	812
Total Phosphorus (mg/L)	0.0178	0.0345	0.0752	29.03%	785
Temperature (degC)	-0.2671	0.7253	1.2604	5.54%	862

According to the *Technical Guidance Manual for Performing Waste Load Allocations* (USEPA 1990), acceptable relative error statistic criteria are 15% for dissolved oxygen and 45% for nutrient parameters (nitrogen, phosphorus, and carbon). The overall relative error statistics for the Christina River model were 8.2% for dissolved oxygen, 15.2% for total nitrogen, 29.0% for total phosphorus, and 17.7% for total organic carbon. Since the relative error statistics for the Christina River EFDC water quality model meet the general guidance criteria published in USEPA (1990), and the model is considered acceptable for conducting TMDL allocation analyses.